Retrieved Latent Heating from TRMM

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Popular Summary

The global hydrological cycle is central to the Earth's climate system, with rainfall and the physics of precipitation formation acting as the key links in the cycle. Two-thirds of global rainfall occurs in the tropics with the associated latent heating (LH) accounting for three-fourths of the total heat energy available to the Earth's atmosphere. In addition, fresh water provided by tropical rainfall and its variability exerts a large impact upon the structure and motions of the upper ocean layer.

In the last decade, it has been established that standard products of LH from satellite measurements, particularly TRMM measurements, would be a valuable resource for scientific research and applications. Such products would enable new insights and investigations concerning the complexities of convection system life cycles, the diabatic heating controls and feedbacks related to meso-synoptic circulations and their forecasting, the relationship of tropical patterns of LH to the global circulation and climate, and strategies for improving cloud parameterizations in environmental prediction models.

The status of retrieved TRMM LH products, TRMM LH inter-comparison and validation project, current TRMM LH applications and critic issues/action items (based on previous five TRMM LH workshops) is presented in this article.

Retrieved Latent Heating from TRMM

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Latent heating (LH) is the heat released or absorbed by the atmosphere as a result of phase changes in water associated with condensation or evaporation of cloud droplets and raindrops, freezing of raindrops, melting of snow and graupel/hail, or the deposition and sublimation of ice particles. The Tropical Rainfall Measuring Mission (TRMM) satellite provides a much needed measurement of rainfall as well as an estimate of the four-dimensional structure of latent (diabatic) heating over the global Tropics (Simpson *et al.* 1988, 1996). TRMM, however, is unable to directly measure LH profiles, so they have to be determined indirectly from the application of physically based models to TRMM precipitation measurements. The general approach is to apply models, ranging in complexity from simple profile shapes to cloud-resolving models (CRMs), to TRMM Precipitation Radar (PR) and/or Microwave Imager (TMI) data (see a review by Tao *et al.* 2006).

Five TRMM LH algorithms have been developed, compared, validated, and applied in the past decade. They are the: (1) Goddard Convective-Stratiform Heating (CSH) algorithm, (2) Hydrometeor Heating (HH) algorithm, (3) Goddard Profiling Heating (GPROF Heating) algorithm, (4) Spectral Latent Heating (SLH) algorithm, and the (5) Precipitation Radar Heating (PRH) algorithm (see Table 1). The CSH, GPROF, and SLH algorithms require the full complement of cloud model data generated by a CRM (or CRMs). Table 1 lists these heating algorithms, the data required to retrieve the heating products, the heating products, key references and developers of each heating algorithm.

	TRMM Data Needed	Heating Products	Key References in Algorithm description	Algorithm Developers
CSH (Convective-Stratiform Heating)	PR, TMI, PR-TMI	Q_1, LH	Tao *et al.* (1993; 2000, 2001)	W.-K. Tao & S. E. Lang
SLH (Spectral Latent Heating)	PR	Q_1, Q_1-Q_R	Shige *et al.* (2004)	S. Shige & Y. N. Takayabu
GPROF (Goddard Profiling Heating)	PR-TMI	Q_1, Q_1-Q_R	Olson *et al.* (1999, 2006)	W. S. Olson & C. D. Kummerow
HH (Hydrometeor Heating)	PR-TMI	LH	Yang *et al.* (1999, 2006)	E. A. Smith & Y. Song
PRH (Precipitation Radar Heating)	PR	LH	Satoh and Noda (2001)	S. Satoh & A. Noda

Table 1 Key characteristics of five different heating algorithms in terms of data requirement, retrieved products. Note that the relationship between Q_1 (apparent heating source, which can be diagnostically determined from an intensive sounding network), LH, Q_1-Q_R and Q_R is: Q_1-Q_R = LH + Eddy transport by clouds. Note that the vertically integrated eddy transport by clouds is zero (no explicit effect on surface rainfall). The papers listed in the table can be found in Tao et al. (2006).

Five TRMM Latent Heating Workshop[1] have been held since May 2001. The major objectives of these workshops were to: (1) discuss the LH algorithm designs and planned improvements, (2) discuss and assess validation schemes and results with diagnostic-type analyses, (3) identify LH requirements and applications issues, (4) determine the uncertainties of latent heating products, (5) identify issues pertaining to use of TRMM and other satellite LH data for global-scale modeling and tropical convection studies, and (6) future validation needs. One recommendation from these workshops was to conduct a TRMM LH inter-comparison and validation project. Seven separate datasets: four field experiment cases[2]: SCSMEX, TRMM-LBA, KWAJEX, and DOE-ARM; two tropical cyclone cases: Atlantic Hurricane Bonnie and Pacific Typhoon Jelewat; and one large-scale regional case: a tropical ocean domain are considered for this inter-comparison project (see Table 2).

	Sampling Ratio (Satellite/diagnostic)	Area Size (km x km)	Date
Case 1a: SCSMEX NESA	53%	665 x 1100	May 18 – June 30 1998
Case 1b: SCSMEX SESA	48%	880 x 880	May 1 – June 30 1998
Case 2: LBA	19%	190 x 190	January 24 – February 28 1999
Case 3: KWAJEX	16%	175 x 175	July 24 – September 14 1999
Case 4a: ARM 2000	38%	400 x 400	March 1 – March 21 2000
Case 4b: ARM 2002	39%	400 x 400	May 25 – June 15 2002
Case 5: Bonnie	N.A.	~500 x 500	1806 UTC, August 22 1998
Case 6: Jelawat	N. A.	~500 x 500	1151 UTC, August 2 2000
Case 7: Ocean	N. A.	4,440 x 9,900	January 1998 – December 2000

Table 2 Satellite sampling and domain size of sounding network for inter-comparison cases. The first four cases are being validated with the apparent heating (Q_1) derived from diagnostic budget calculations based on observations from special radiosonde or combined radiosonde-Doppler radar networks. The two tropical cyclones (Cases 5 and 6) allow for the algorithm-generated instantaneous LH profiles to be compared -- but without validation information. In the final case, the inter-comparisons focused on a hierarchy of space-time scale variations (including inter-annual variations) over large-scale regional domains involving tropical ocean environments.

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[1] The summary of the 4th TRMM LH workshop was published recently (Tao *et al.* 2007).

[2] SCSMEX *(South China Sea Monsoon Experiment)* took place over South China Sea (SESA and NESA stands for south and north enhanced sounding arrays, respectively). TRMM-LBA *(Large Scale Biosphere-Atmosphere Experiment in Amazonia)* took place in Rondonia, Brazil. KWAJEX (*TRMM Kwajalein Experiment)* took place around Kwajalein Atoll, Republic of Marshall Islands. DOE-ARM *(Department of Energy-Atmospheric Radiation Measurement)* Program supports cloud-radiation experiments in Oklahoma at Southern Great Plains-Cloud and Radiation Test Bed (SGP-CART) site.

The inter-comparison results are illustrated here using the SCSMEX SESA case (Fig. 1). The sounding-estimated Q_1 (two different averaging areas) and satellite-derived Q_R are also shown for comparison. The CSH (Q_1) and SLH (both Q_1-Q_R and LH) algorithms agree with the sounding-estimated Q_1 in terms of amplitude of peak heating and having a broad heating peak. However, their retrieved peak heating level is slightly higher than that estimated from the soundings. GPROF-retrieved heating (Q_1 and Q_1-Q_R) also agrees with the sounding estimates, but has smaller amplitude (especially in the lower troposphere) compared to the other algorithms. The HH-retrieved heating agrees with that estimated from sounding data in terms of altitude of maximum heating and having positive heating in the upper troposphere (above 10 km). Its retrieved heating is larger than the other algorithms. The PRH-retrieved heating profile has the lowest maximum heating altitude. These preliminary results are quite encouraging despite sampling issue (Table 2), because each algorithm's retrieved heating structure captured some of the major characteristics estimated from the sounding network.

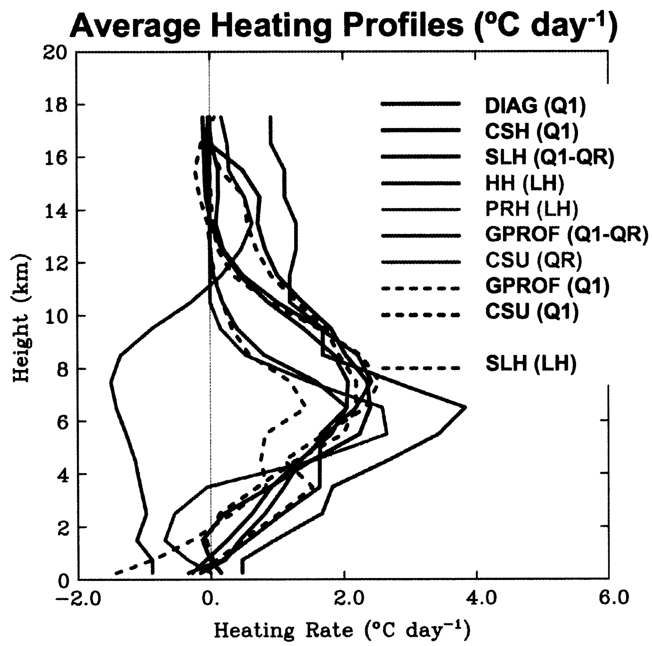

Fig. 1 *Space/time-averaged heating profiles Case 1b: SCSMEX-SESA (right panel) regions. Profiles for different heating terms are obtained from five different satellite algorithms, i.e., solid green lines from CSH, solid violet lines from HH, solid red and dashed red lines from GPROF, solid blue and dashed blue lines from SLH, and solid orange lines from PRH.* Q_1 *profiles from CSU's diagnostic calculations are presented for two different averaging areas, i.e., solid black lines (DIAG) from within SESA sounding arrays and dashed black lines (CSU) from SESA study area rectangular gridded arrays. Satellite-derived* Q_R *profiles from CSU, i.e., solid turquoise lines (CSU), are also associated with gridded arrays.*

In the last decade, standard LH products from TRMM measurements have been developed for scientific research and applications (see Table 3). Such products enable new insights and investigations of the complexities of convective life cycles, the diabatic heating controls and feedbacks of meso-synoptic circulations and their forecasts, the relationship of patterns of tropical LH to the global circulation and climate, and of strategies for improving cloud

parameterizations in environmental prediction models. The distributions of rainfall and inferred heating can be used to advance understanding of the global energy and water cycle. In addition, this information can be used for global circulation and climate models for validating and improving their parameterizations.

	Heating Products used for applications	*> Ten Applications - 5 papers*
Drs. Krishnamurti, Rajendran (FSU, MRI)	CSH	Global Model Assimilation
Dr. A. Del Genio (GISS)	CSH	Large-Scale Modeling Validation (Level of Max Heating)
Dr. A. Hou (GSFC)	GPROF	Global Model Assimilation
Dr. D. Waliser (JPL)	CSH & GPROF	Comparison between Global Model (ECMWF) and TRMM Derived for MJO
Dr. C. Zhang (U. Miami)	CSH/SLH	LH and Large-Scale Dynamic (MJO and Shallow Meridional Circulation)
Dr. X. Zhang (U. Colorado)	CSH	Relationship between LH and Mesosphere and Low Thermosphere Solar Tides
Dr. W. Lau (GSFC)	CSH	Evolution of MJO
Dr. R. Small (U. Hawaii)	GPROF/CSH	Tropical Circulation Response to LH Anomalies
Dr. P. Webster (Georgia Tech.)	GROF/CSH	Monsoon
Drs. J. Morita/Y. N. Takayabu (CCSR/U. Tokyo)	SLH	LH Structures of MJO

Table 3 Key scientists using TRMM derived LH products for specific applications. MJO stands for Madden-Julian oscillation (MJO).

In future, there will be close collaboration among LH algorithm developers and as well as some consolidation of their products (a version 1 will be available in the near future with detailed advice concerning limitations and appropriate applications). Therefore, the users could be made aware of the choices and pick the appropriate algorithm for a given application. It is also expected that results from all seven cases will be compared and validated, and the relationship of LH to radiative heating will be further explored.

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